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CALIBRATION OF BREECH EROSION GAGE FOR 5.56MM CHROME-PLATED BORES

DECEMBER 1975

By

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ABSTRACT

A firing test was conducted to provide a data base for the optimization of the design of a breech erosion gage for 5.56mm chrome plated rifle barrels. Nine separate gage diameters, 27 barrels, three rates of fire, two types of ammunition and three barrel manufacturers were represented in the test to give the broadest possible data base. Analysis of the firing test led to the determination that the optimum gage diameter range is from .2210 - .2218", and that barrels should be rejected when gages within this diametrical range penetrate more than 2.62" beyond the rear of the locking lugs on the barrel.

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A firing test was conducted to provide a data base for the optimization of the design of a breech erosion gage for 5.56mm chrome plated rifle barrels. Nine separate gage diameters, 27 barrels, three rates of fire, two types of ammunition and three barrel manufacturers were represented in the test to give the broadest possible data base. Analysis of the firing test led to the determination that the optimum gage diameter range is from .2210 - .2218 in, and that barrels should be rejected when gages within this diametrical range penetrate more than 2.62 in beyond the rear of the locking lugs on the barrel.

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BACKGROUND

The support of any fielded item includes provision of means for the determination of the serviceability of that item. For many years, the serviceability of the Army's rifle barrels has been determined qualitatively by a visual check and quantitatively by insertion of a plug gage into the bore from the breech. The depth of penetration of the plug gage is then related to the amount of erosion of the rifling lands.

The use of a plug gage in the breech is predicated on the hypothesis that erosion of the bore is the principle cause of failure of a barrel to meet its accuracy, velocity, yaw, or structural integrity requirements. In actual practice, it has been found that accuracy is usually the first requirement failed by rifle barrels. Thus, the bore erosion gage is calibrated by relating its penetration to weapon accuracy.

Until 1971, all M16A1 rifle barrels were supplied to the field with unplated bores and their serviceability was determined by the usual type of breech erosion gage. Introduction of chrome-plated bores for the M16A1 in 1971 necessitated recalibration of the gage. This report summarizes that recalibration project.

OBJECTIVE

The original purpose of this test program was the recalibration of the gauging length of the breech erosion gage. However, during the planning of the program, the objective was expanded to include optimization of the gage's diameter. Thus, in effect, the program was directed toward the identification of an optimum gage for chrome plated M16A1 rifle bores.

In the interest of maximizing the return from the program, two additional objectives were identified which could be met with little additional effort. The first of the two objectives was to establish a performance baseline for 5.56mm barrels against which all future tests could be conducted. The other objective was to study the mutation of projectile engraving characteristics throughout the barrels' service life for a broad variety of service conditions.

SCOPE OF PROGRAM

Twenty-seven M16A1 Rifle Barrels, nine from each of the three producers, were selected for this program after a rigorous dimensional and visual inspection as well as an initial test firing to assure their conformance to drawing and specification requirements. Each of the three producers used a unique process to fabricate his barrels. Consequently, three distinctly different bore configurations, all of which met the requirements of the production technical data package, were utilized in this test.

Three rates of fire (20 rd/min, 60 rd/min, and 100 rd/min) and two types of ammunition (M193 Ball and M196 Tracer) were fired during the test. Two barrels from each contractor were fired at each rate with M193 Ball ammunition. One barrel from each contractor was fired at each rate with M196 Tracer ammunition. The schedules for all barrels are shown in Table I.

Periodic cooling, cleaning, visual inspections, accuracy firings, gage penetration tests, projectile trappings, and muzzle velocity tests were conducted at appropriate intervals throughout the test. The trapped projectiles were quantitatively inspected at 10X magnification for engraving mutations. The results of that work are recorded in TR #R-TR-75-029, "Projectile Engraving Mutations and Their Relationships to Accuracy of the M16A1 Rifle", June 1975. All other test data is recorded in the GEN Thomas J. Rodman Laboratory Weapons Test Division's report titled, "Bore Erosion Gage Calibration Test for M16A1, 5.56mm Rifle Barrels with Chrome Lined Bore", dated 11 December 1974.

Details of the test procedure are given in the test plan "Breech Erosion Gage Calibration Test Program for M16A1 Rifle Chrome Plated Barrel Bores" which is included as Appendix A.

SUMMARY OF RESULTS

The data, as collected, is far too voluminous to be included in this report. Only data which proved to be germane to the immediate problem will be included. Sources for the entire data have previously been given in the Scope of Program section. Data that is included in this report will be presented in reduced form both to save space and to facilitate the reader's comprehension.

Table I contains the barrel manufacturer's code, rate of fire, and type of ammunition fired for each barrel. Table II records the penetration of each gage in each barrel and the accuracy of each barrel at test initiation. Table III shows the length of each barrel's life and the penetration of each gage at the end of each barrel's life. Accuracy data for the barrels throughout their lives is recorded in Tables IV, V, and VI. Table VII lists the diameter of each gage and the mean and standard deviation of the penetration of each gage in all ball-fired barrels.

Inclusion of the test plan as Appendix A will allow the reader to determine the extent of the data collected, and the reader can then contact this Laboratory for any data that he desires. The pre-test inspections and accuracy firings referenced in Section 5 of the test plan resulted in the selection of twenty-seven barrels which were satisfactory for the test. Once the test hardware had been selected, testing was conducted and test data collected to determine:

(1) The accuracy life of each barrel,

(2) the optimum gage diameter,

(3) and gage penetration which best corresponds to the end of accuracy life.

The basis for the determination of the end of a barrel's accuracy life is the field rejection criteria of seven inches extreme spread for a ten-shot target at a range of 100 yards.

TABLE I
FIRING SCHEDULE

BARREL MANUFACTURER	BARREL NUMBER	RATE OF * FIRE (RPM)	TYPE OF ** AMMO
A	A1	20	M193 Ball
A	A2	20	M193 Ball
A	A3	20	M196 Tracer
A	A4	60	M193 Ball
A	A5	60	M193 Ball
A	A6	60	M196 Tracer
A	A7	100	M193 Ball
A	A8	100	M193 Ball
A	A9	100	M196 Tracer
B	B1	20	M193 Ball
B	B2	20	M193 Ball
B	B3	20	M196 Tracer
B	B4	60	M193 Ball
B	B5	60	M193 Ball
B	B6	60	M196 Tracer
B	B7	100	M193 Ball
B	B8	100	M193 Ball
B	B9	100	M196 Tracer
C	C1	20	M193 Ball
C	C2	20	M193 Ball
C	C3	20	M196 Tracer
C	C4	60	M193 Ball
C	C5	60	M193 Ball
C	C6	60	M196 Tracer
C	C7	100	M193 Ball
C	C8	100	M193 Ball
C	C9	100	M196 Tracer

*Cooled after each 100 rounds.
**Ammo listed was used for endurance firing. M193 Ball was fired for all accuracy testing of all weapons.

TABLE II
PENETRATION DATA AT TEST INITIATION

BARREL NUMBER	RATE OF FIRE	AMMO	EXTREME SPREAD	PENETRATION OF GAGE NO 1	2	3	4	5	6	7	8	9
A1	20	M193	3.8	2.39	2.38	2.37	2.38	2.37	2.36	2.36	2.34	2.32
A2	20	M193	4.7	2.39	2.38	2.37	2.36	2.36	2.37	2.35	2.33	2.33
A3	20	M196	3.5	2.40	2.39	2.37	2.38	2.36	2.36	2.36	2.34	2.32
A4	60	M193	3.5	2.40	2.39	2.37	2.34	2.35	2.37	2.35	2.34	2.33
A5	60	M193	3.3	2.39	2.40	2.36	2.34	2.35	2.35	2.35	2.34	2.33
A6	60	M196	3.2	2.39	2.39	2.36	2.35	2.37	2.37	2.36	2.33	2.32
A7	100	M193	4.2	2.42	2.40	2.38	2.40	2.38	2.38	2.36	2.34	2.33
A8	100	M193	4.2	2.40	2.39	2.37	2.38	2.36	2.36	2.35	2.33	2.31
A9	100	M196	2.7	2.39	2.38	2.36	2.38	2.36	2.37	2.36	2.34	2.33
B1	20	M193	3.2	2.40	2.38	2.36	2.36	2.36	2.37	2.36	2.35	2.35
B2	20	M193	3.7	2.40	2.39	2.38	2.39	2.37	2.37	2.35	2.34	2.33
B3	20	M196	4.0	2.40	2.40	2.38	2.40	2.38	2.37	2.37	2.35	2.34
B4	60	M193	4.8	2.41	2.40	2.38	2.37	2.37	2.38	2.39	2.36	2.33
B5	60	M193	3.6	2.40	2.39	2.34	2.34	2.34	2.35	2.35	2.34	2.32
B6	60	M196	3.8	2.38	2.38	2.34	2.33	2.33	2.36	2.34	2.33	2.31
B7	100	M193	2.5	2.38	2.38	2.35	2.34	2.34	2.35	2.36	2.33	2.33
B8	100	M193	4.4	2.40	2.39	2.37	2.38	2.36	2.37	2.36	2.34	2.33
B9	100	M196	3.6	2.41	2.40	2.38	2.39	2.38	2.37	2.37	2.35	2.33
C1	20	M193	4.5	2.78	2.62	2.56	2.42	2.40	2.35	2.34	2.32	2.31
C2	20	M193	3.4	3.00	2.82	2.74	2.61	2.56	2.41	2.35	2.33	2.32
C3	20	M196	3.7	2.98	2.72	2.66	2.56	2.50	2.36	2.34	2.33	2.31
C4	60	M193	4.3	2.73	2.67	2.57	2.47	2.41	2.38	2.37	2.35	2.33
C5	60	M193	3.3	2.62	2.62	2.46	2.36	2.37	2.35	2.34	2.33	2.32
C6	60	M196	3.7	3.03	2.88	2.60	2.47	2.48	2.41	2.39	2.38	2.37
C7	100	M193	3.3	2.72	2.57	2.54	2.46	2.41	2.35	2.34	2.33	2.31
C8	100	M193	4.7	2.98	2.69	2.65	2.51	2.43	2.35	2.33	2.32	2.31
C9	100	M196	4.3	3.03	2.64	2.61	2.51	2.50	2.39	2.37	2.35	2.33

TABLE III
PENETRATION DATA AT END OF USEFUL BARREL LIFE
(3RD ORDER REGRESSION)

BARREL NUMBER	RATE OF FIRE	AMMO	ROUNDS FIRED	PENETRATION OF GAGE NO 1	2	3	4	5	6	7	8	9
A1	20	M193	8,000	2.55	2.56	2.52	2.50	2.50	2.51	2.48	2.47	2.43
A2	20	M193	10,000	2.59	2.57	2.55	2.55	2.55	2.56	2.54	2.53	2.48
A3	20	M196	29,000	4.14	4.14	4.11	4.06	4.13	4.09	3.94	3.83	3.71
A4	60	M193	6,000	2.48	2.48	2.46	2.44	2.44	2.45	2.44	2.41	2.35
A5	60	M193	8,000	2.52	2.51	2.49	2.48	2.46	2.47	2.45	2.37	2.34
A6	60	M196	>15,000*	3.58	3.55	3.37	3.33	3.34	3.26	3.17	3.08	3.04
A7	100	M193	5,000	2.51	2.50	2.47	2.47	2.47	2.48	2.48	2.41	2.34
A8	100	M193	6,000	2.58	2.56	2.53	2.51	2.51	2.52	2.50	2.46	2.37
A9	100	M196	>15,000*	4.30	4.26	4.24	4.06	4.00	3.89	3.78	3.75	3.45
B1	20	M193	16,000	2.82	2.78	2.74	2.72	2.72	2.73	2.68	2.63	2.61
B2	20	M193	21,000	3.02	3.02	2.99	2.99	2.99	2.99	2.96	2.93	2.93
B3	20	M196	>30,000*	6.64	6.60	6.56	6.36	6.36	6.35	6.24	6.15	5.93
B4	60	M193	11,000	2.68	2.64	2.62	2.60	2.60	2.59	2.58	2.55	2.53
B5	60	M193	9,000	2.58	2.56	2.54	2.51	2.52	2.52	2.50	2.47	2.46
B6	60	M196	>15,000*	5.02	4.94	4.89	4.78	4.76	4.71	4.54	4.43	4.25
B7	100	M193	7,500	2.62	2.60	2.55	2.56	2.56	2.56	2.53	2.51	2.46
B8	100	M193	10,000	2.80	2.76	2.74	2.72	2.72	2.69	2.64	2.61	2.58
B9	100	M196	>15,000*	5.46	5.38	5.36	5.22	5.12	4.83	4.76	4.75	4.33
C1	20	M193	20,000	2.83	2.80	2.80	2.76	2.76	2.77	2.74	2.71	2.69
C2	20	M193	>30,000*	3.39	3.38	3.35	3.34	3.34	3.33	3.26	3.22	3.08
C3	20	M196	>30,000*	4.66	4.62	4.62	4.56	4.56	4.53	4.49	4.40	4.33
C4	60	M193	12,000	2.68	2.62	2.59	2.52	2.52	2.53	2.52	2.49	2.45
C5	60	M193	12,000	2.62	2.58	2.56	2.52	2.52	2.51	2.50	2.47	2.45
C6	60	M196	>15,000*	3.51	3.50	3.49	3.43	3.41	3.40	3.35	3.14	2.94
C7	100	M193	7,500	2.54	2.52	2.48	2.45	2.45	2.46	2.44	2.41	2.40
C8	100	M193	8,000	2.64	2.54	2.52	2.46	2.46	2.47	2.44	2.41	2.39
C9	100	M196	>15,000*	4.06	4.03	4.00	3.88	3.90	3.87	3.82	3.77	3.71

>*The accuracy of this barrel was still satisfactory at the conclusion of the test.

TABLE IV
ACCURACY DATA OF 20 ROUND/MIN RIFLES*

	BARREL NO.								
ROUNDS FIRED	A1	B1	C1	A2	B2	C2	A3	B3	C3
0	3.8	3.2	4.5	4.7	3.7	3.4	3.5	4.0	3.7
1000	4.9	4.3	3.8	7.5	4.7	4.3	3.7	2.7	3.3
2000	3.1	3.4	3.0	6.7	3.3	4.4	3.8	3.5	2.9
3000	3.5	3.1	4.1	6.5	4.0	4.3	4.2	2.3	3.1
4000	4.2	3.5	4.2	4.1	4.8	4.8	5.6	2.9	2.6
5000	4.6	4.2	4.1	5.4	4.0	4.2	4.7	3.6	3.7
6000	3.6	4.6	3.9	4.4	3.5	3.3	6.7	5.3	4.7
7000	4.4	3.3	3.6	6.1	4.1	4.5	5.4	3.1	5.9
8000	6.7/	4.5	3.6	5.5	3.1	4.0	4.8	3.0	3.4
9000	8.3	4.3	3.6	7.1	4.7	4.0	4.5	3.1	4.4
10000	8.3	5.8	6.4	7.2/	3.5	4.3	5.8	2.9	3.5
11000	9.2	4.5	5.0	8.7	3.8	3.4	5.7	2.8	5.2
12000	10.6	4.7	4.5	8.2	4.9	5.5	7.0/	3.5	3.6
13000	11.6	7.4	5.3	9.6	8.5	4.6	8.9	3.4	3.1
14000	14.0	7.2	5.8	8.9	7.2	3.8	5.5	3.1	4.3
15000	11.6	9.2	7.4	8.5	6.2	5.9	5.5	2.9	3.7
16000	13.8	7.5/	6.0	11.8	7.7	5.8	8.5	3.4	3.3
17000	10.7	8.4	5.7	11.0	6.9	5.2	5.6	3.6	3.9
18000	11.3	7.9	7.0	12.1	7.0	4.9	6.2	3.4	4.5
19000	11.5	7.3	6.3	10.8	4.8	6.1	4.9	3.2	3.2
20000	12.9	8.5	6.7/	13.8	5.2	4.9	5.0	4.0	4.1
21000	13.3	7.2	7.9	15.5	5.1/	4.7	5.1	3.6	4.1
22000	11.2	5.7	8.9	12.2	6.3	5.2	7.2	3.2	4.8
23000	14.5	9.8	6.5	10.5	8.4	6.5	5.1	3.6	3.9
24000	11.4	8.7	7.6	14.3	7.0	5.1	5.8	3.0	5.2
25000	12.3	6.3	8.9	13.4	7.6	7.3	6.3	6.2	7.1
26000	16.1	9.1	10.9	13.9	8.9	6.4	6.3	3.1	4.9
27000	12.4	8.4	11.2	13.1	8.3	6.5	7.3	3.4	4.3
28000	12.1	6.9	19.3	11.4	7.7	6.2	5.5	3.6	4.5
29000	8.8	8.5	10.0	12.3	11.0	4.5	7.8	3.5	4.4
30000	9.3	7.9	13.5	13.3	8.9	---	6.8	3.8	5.7

*Each data point is the average extreme spread of three ten-shot targets.
_/ End of useful barrel life as determined by third order regression.

TABLE V
ACCURACY DATA OF 60 ROUND/MIN RIFLES*

	BARREL NO.								
ROUNDS FIRED	A4	B4	C4	A5	B5	C5	A6	B6	C6
0	3.5	4.8	4.3	3.3	3.6	3.3	3.2	3.8	3.7
1000	2.7	4.0	3.7	3.7	3.6	2.8	3.6	2.9	4.2
2000	3.7	3.2	3.4	3.7	3.3	4.9	4.6	3.6	3.6
3000	4.0	3.7	3.6	3.4	3.7	4.6	4.6	3.0	3.5
4000	6.7	3.5	4.0	5.4	5.3	4.1	3.6	4.8	3.3
5000	6.7	3.8	3.4	5.2	4.3	5.8	4.2	4.0	4.1
6000	7.0/	4.8	5.2	5.7	4.2	4.9	3.5	3.0	3.7
7000	8.6	4.5	5.3	5.8	4.2	5.4	4.5	3.6	3.7
8000	8.2	5.4	4.2	7.6/	4.7	4.6	4.2	2.8	3.2
9000	8.4	5.1	5.4	7.4	8.0/	5.1	4.3	2.4	5.4
10000	8.9	9.0	8.1	9.6	7.2	9.1	3.2	2.5	5.5
11000	11.4	5.5/	4.9	10.6	10.3	7.1	4.1	3.2	4.4
12000	10.8	9.2	5.7/	10.4	7.1	6.9/	4.0	3.3	4.0
13000	11.3	8.8	7.3	12.1	9.0	5.6	4.0	4.5	4.4
14000	11.2	7.9	8.0	13.0	10.1	8.8	3.7	5.6	4.3
15000	13.1	11.2	11.0	8.5	8.0	9.5	4.9	2.9	4.5

*Each data point is the average extreme spread of three ten-shot targets.

_/ End of useful barrel life as determined by third order regression.

TABLE VI
ACCURACY DATA OF 100 ROUND/MIN RIFLES*

	BARREL NO.								
ROUNDS FIRED	A7	B7	C7	A8	B8	C8	A9	B9	C9
0	4.2	2.5	3.8	4.2	4.4	4.7	2.7	3.6	4.3
500	3.4	3.0	3.5	4.2	5.8	3.9	4.0	4.2	3.8
1000	4.4	4.5	4.4	3.2	5.0	3.8	3.8	4.1	5.6
1500	3.9	3.4	3.5	5.3	5.7	4.2	4.1	4.4	4.1
2000	4.1	3.4	3.4	3.6	4.3	3.8	3.4	3.3	4.3
2500	3.6	3.7	5.2	3.9	4.2	4.0	3.8	2.8	4.3
3000	4.1	4.0	3.4	3.5	4.0	4.7	4.1	2.8	3.7
3500	5.1	3.9	4.6	4.2	4.9	4.4	3.3	3.4	3.7
4000	4.5	3.7	4.4	5.4	3.7	5.1	4.4	3.5	3.7
4500	7.7	3.9	5.2	7.3	3.6	6.8	5.3	3.8	3.1
5000	6.6/	4.9	5.1	6.8	4.5	3.9	4.7	3.8	4.4
5500	8.9	6.3	7.2	6.3	3.8	3.8	4.9	3.6	4.3
6000	6.9	7.5	5.9	6.2/	5.9	6.0	3.8	3.7	5.0
6500	8.6	7.5	8.2	8.4	5.3	6.0	4.6	4.1	5.3
7000	7.5	5.3	4.9	8.6	4.4	4.2	3.7	4.3	3.3
7500	10.5	5.5/	7.1/	10.5	6.9	5.6	3.8	5.1	4.3
8000	11.1	7.3	6.6	8.3	4.5	7.4/	3.5	5.2	3.6
8500	13.1	8.3	9.1	11.0	5.3	6.9	4.8	3.5	4.0
9000	9.1	7.3	9.2	9.3	6.6	8.3	4.3	3.9	4.5
9500	13.7	8.8	9.0	12.3	7.8	9.2	4.0	3.1	4.0
10000	11.7	10.7	8.4	8.0	7.4/	9.3	3.6	3.3	4.3
10500	12.1	9.7	8.9	10.1	5.2	9.4	4.5	3.2	4.3
11000	14.6	10.3	11.8	16.1	8.5	10.0	4.6	3.4	3.5
11500	13.7	10.4	13.0	15.0	8.2	10.8	6.8	4.5	5.2
12000	14.4	8.4	13.6	14.4	5.3	14.4	5.7	3.5	4.6
12500							6.1	5.1	3.3
13000							5.0	3.4	4.4
13500							4.2	3.9	4.0
14000							4.4	4.5	3.8
14500							6.0	4.5	3.2
15000							4.4	3.4	5.0
15500							4.6	3.4	3.9

*Each data point is the average extreme spread of three ten-shot targets.
_/ End of useful barrel life as determined by third order regression.

TABLE VII
PENETRATIONS IN BARRELS
A1, A2, A4, A5, A7, A8
B1, B2, B4, B5, B7, B8
C1, C2, C4, C5, C7, C8

NO.	GAGE DIAMETER	NEW RIFLE PENETRATION MEAN	NEW RIFLE PENETRATION STD DEV	PENETRATION AT END OF LIFE MEAN	PENETRATION AT END OF LIFE STD DEV
1	.2204	2.53	.214	2.69	.222
2	.2206	2.48	.142	2.67	.224
3	.2208	2.44	.119	2.64	.225
4	.2210	2.40	.071	2.62	.229
5	.2212	2.38	.051	2.62	.229
6	.2218	2.37	.016	2.62	.225
7	.2223	2.35	.013	2.59	.212
8	.2228	2.34	.010	2.56	.213
9	.2234	2.32	.010	2.52	.202

ANALYSIS OF RESULTS

At first glance it would seem that determining the end of a barrel's life should be a relatively straight-forward matter. After all, the rejection criteria is well defined and the measurement of the targets is simple and precise.

For rifles whose measured extreme spread increases through the region of interest as the number of rounds it has fired increases, the determination is not complicated. For instance, the life of barrel A1 in Table IV is obviously 9,000 rounds. Unfortunately, some rifles demonstrate oscillating variations in their accuracy in the region of interest. Barrel C1 in Table IV exhibits this phenomenon. At 15,000 rounds, its average extreme spread is 7.4 inches. At 17,000 rounds the average extreme spread has diminished to 5.7 inches.

Numerous philosophies of how to determine the life of these ill-behaved rifles were willingly provided by interested observers of the program. Persons who literally and narrowly interpreted the user's requirement were of the opinion that a barrel's useful life was ended the first time the rifle shot one target of 7 inches extreme spread or larger. This philosophy certainly has merit, especially from the soldier's standpoint. However, it is a harsh interpretation which does not consider the limitations of samples and the target-to-target accuracy variations commonly encountered. For example, this philosophy would terminate barrel A2's life at 1,000 rounds (see Table IV) when, in fact, it shot acceptably from 2,000 through 8,000 rounds.

On the other extreme, persons whose main concern was logistics cost argued that a barrel was good until it always shot groups larger than seven inches. This philosophy doesn't seem to be in consonance with the intent of the user's requirement.

A more logical approach is to plot regression lines through the data and to determine barrel life by noting when the regression line passes 7 inches extreme spread. Having decided upon this course of action, only one question remained to be answered, that being the determination of the most appropriate order for the regression line. First, second, third, and fourth order regression lines were plotted for informational purposes. The first order regression line was rejected since, in many cases, it was obvious that the relationship between extreme spread and rounds fired was not linear. The second order regression line was not chosen because logic would indicate that there should be a maximum limit to the extreme spread of a 10 shot group of even tumbling bullets. This logic was reinforced by prior testing during which completely worn out barrels rarely shot groups which exceeded 30 inches extreme spread.

Thus, the third order curve appeared to best fit the nature of the phenomenon. It was also noted that third and fourth order curves gave nearly the same life. Using third order regression, the life of each barrel in rounds and the penetration of each gage at the end of the barrel's life were determined. This data is shown in Table III. Table II contains penetration data for each barrel at test initiation. Table VII, which records gage diameter, average new rifle penetration, and average penetration at end of barrel life for all ball-firing barrels, was developed from Tables II and III. It is Table VII which forms the basis for gage selection. However, before the gage selection process is discussed, a few general comments are in order.

The original concept was to have one gage design for all chrome-plated barrels regardless of manufacturer, firing schedule, or type of ammunition fired. However, a review of the test results disclosed the lack of practicality of the original concept. Even a cursory examination of Table III reveals that the barrels which were fired solely with M196 Tracer ammunition had much longer lives and suffered much more gage penetration before the end of their accuracy lives than did the barrels which fired M193 Ball ammunition. Inclusion of the barrels which fired tracer ammunition would significantly alter the calibration point of the gage, causing many ball ammunition firing barrels to be retained in the system far beyond their useful life.

Previous experience has demonstrated that very few barrels are ever worn out by erosion in combat areas. Only those barrels used in training areas survive long enough to be worn out by erosion. Training areas use practically all ball ammunition; therefore, in reality the gage in the field will only have a practical application on training base rifles which have been fired with ball ammunition. This rationale formed the basis for a decision to use only those rifles which had fired ball ammunition in the calibration of the gage.

The data shown in Table VII makes gage design relatively straightforward. The columns titled "Penetration at End of Life" demonstrate that the mean and standard deviation of that penetration are relatively independent of gage diameter within a dimensional band from .2210 through .2218 inches. Obviously acceptance or rejection of a barrel should not be a function of gage diameter within the allowed tolerance band of the gage design. It, therefore, behooves us to select our gage diameter and its associated tolerance range such that penetration does not change significantly regardless of whether the particular gage being used lies on the large or small side of the acceptable tolerance zone. Gages built anywhere within this diametrical range (.2210 to .2218) would give consistent results.

Previous gages have been designed with a $\pm$ .0001 tolerance on their diameters. If a significant gage cost reduction could be obtained by increasing the gage's diametrical tolerance, test results indicate that a gage diameter and tolerance of .2214 $\pm$ .0004 could be utilized without detrimental effects on gaging uniformity.

The determination of the gage penetration at which the barrels should be discarded follows directly from the gage diameter range just chosen. Table VII displays 2.62 inches of gage penetration from the rear of the locking lugs on the barrel as the cut-off point for gages of diameter .2210 - .2218.

CONCLUSIONS

The following six conclusions can be drawn from this program:

1. M16A1 Rifle barrels which are fired solely with M196 Tracer ammunition have significantly longer useful accuracy lives than M16A1 Rifle barrels fired with M193 Ball ammunition.

2. M16A1 Rifle barrels fired solely with M196 Tracer ammunition suffer much greater erosion before they become inaccurate than do M16A1 Rifle barrels fired with M193 Ball ammunition.

3. Erosion gage penetration at the end of a barrel's accuracy life is much less affected by barrel manufacturer and rate of fire than by type of ammunition fired.

4. Erosion gage penetration at the end of barrel life is relatively independent of gage diameter for diameters within the range of .2210 - .2218.

5. For all barrels which were fired with M193 Ball ammunition, gages whose diameters lie between .2210 - .2218 gave a mean penetration of 2.62" from the rear of the barrel locking lugs.

6. A potential gage cost reduction exists through relaxation of diametrical tolerance.

RECOMMENDATIONS

1. Gage diameter be selected between .2210 and .2218.

2. Consideration should be given to the financial advantages of a gage diameter tolerance range of $\pm.0002$ to $\pm.0004$" in lieu of the previously required tolerance range of $\pm.0001$.

3. For gages whose diameters lie between .2210 and .2218, gage rejection calibration should be established such that barrels are rejected when the gage penetrates 2.62" beyond the rear of the locking lugs on the barrel.

APPENDIX A

BREECH EROSION GAGE CALIBRATION TEST PROGRAM FOR M16A1 RIFLE CHROME PLATED BARREL BORES

1. Material for Test:

a. Twenty-seven new Code B M16A1 Rifles with chrome-plated barrel bores.

b. Nine Code A replacement barrels with chrome-plated bores.

c. Nine Code C upper receiver and barrel assemblies with chrome-plated bores.

d. 300,000 rounds of M193 Ball ammunition per MIL-C-9963.

e. 165,000 rounds of M196 Tracer ammunition per MIL-C-60111.

f. 30,000 rounds of M193 Ball ammunition qualified for accuracy with group mean radius of 1.2 to 1.4 inches at 200 yards per MIL-C-9963.

2. Test Program Request No: TPR-SAL-73-P025

3. Test Installations: SARRI-LE-T and SARRI-QM

4. Purpose of Test:

a. The purpose of this test is to calibrate the breech erosion penetration gage as a field criterion for determining the accuracy and serviceability of M16A1 Rifle barrels with chrome-plated bores.

b. To establish a comparative base line upon which to judge future 5.56mm barrel testing.

5. Test Preparation and Maintenance:

a. Prior to testing, SARRI-LS-P will identify all barrel assemblies by marking M1-M9 for the nine Code A barrels; C1-C9 for the nine Code B upper receiver and barrel assemblies; GM1-GM9 for the nine Code C upper receiver and barrel assemblies. All markings will be located directly in front of the front sight assembly on the barrel.

b. Prior to weapon firing by SARRI-LE-T, nine Code B upper receiver and chrome barrel assemblies, nine Code A chrome barrel assemblies, and nine Code C upper receiver and chrome barrel assemblies will be delivered to SARRI-QM (Fred Smith) for the purpose of recording the following data:

(1) Land and groove diameters at two inch increments starting from the muzzle end, determined by air gaging, and one reading at land and

groove diameters as close to the breech end as possible. Land and groove diameters will be re-measured at same location subsequent to firing by SARRI-LE-T.

(2) Comments regarding bore conditions after inspection by TV borescope.

(3) Barrel straightness acceptable or non-acceptable after inspection by drop gage.

(4) Bullet seat diameter measured on chamber cast of each barrel.

(5) Forcing cone angle measured on chamber cast of each barrel.

c. All weapons will then be delivered to SARRI-LE-T by SARRI-LS-P. Weapons will be assembled such that nine new rifles are equipped with Code A barrels with chrome-plated bores, nine rifles with Code B barrels with chrome-plated bores, and nine rifles with Code C barrels with chrome-plated bores.

d. All weapons shall be inspected and accuracy tested by SARRI-LE-T prior to firing of test to determine their completeness and suitability for the test.

e. Necessary maintenance shall be performed by the testing agency in accordance with the applicable TM's and the instructions stated herein.

6. Data to be Recorded:

a. Date

b. Test Title

c. Identification of all weapons to be tested by serial number of rifle and barrel designation of attached barrel.

d. Identification of gunner(s) and all participants.

e. All stoppages, malfunctions or other irregularities.

f. Extremem spread, extreme horizontal, extreme vertical, figure of merit, and mean radius for each target. Targets shall be identified by barrel designation and number of rounds fired prior to accuracy check.

g. Breech penetration inspection results for each barrel with gages supplied by SARRI-LS-P (T. Nathan). Data to be recorded on sheets provided by SARRI-LS-P include penetration in inches, barrel designation, gage diameter, and rounds fired prior to inspection.

h. Muzzle velocities recorded in ft/sec and barrel designation.

i. Any unusual occurrences or conditions.

TEST LENGTH AND RATE SHCEDULE

RATE	NO OF WEAPONS & BBL DESIGNATION	AMMO TYPE	TEST LENGTH* PER WEAPON
20 rds/min	6 - 2 Code A (M1,M2) 2 Code B (C1,C2) 2 Code C (GM1,GM2)	M193 Ball	30,000 rds
20 rds/min	3 - 1 Code A (M3) 1 Code B (C3) 1 Code C (GM3)	M196 Tracer	30,000 rds
60 rds/min	6 - 2 Code A (M4,M5) 2 Code B (C4,C5) 2 Code C (GM4,GM5)	M193 Ball	15,000 rds
60 rds/min	3 - 1 Code A (M6) 1 Code B (C6) 1 Code C (GM6)	M196 Tracer	15,000 rds
100 rds/min	6 - 2 Code A (M7,M8) 2 Code B (C7,C8) 2 Code C (GM7,GM8)	M193 Ball	10,000 rds
100 rds/min	3 - 1 Code A (M9) 1 Code B (C9) 1 Code C (GM9)	M196 Tracer	10,000 rds
TOTALS	27 WEAPONS	M193 M196	330,000 rds 165,000 rds

*At the discretion of SARRI-LS-P personnel, testing of a given weapon may be terminated prior to test length shown.

Firing Sequence:

All weapons designated to be fired at rates of 20 rds/min and 60 rds/min as shown on rate schedule will be fired in the following sequence:

a. 100 rounds semi-automatic

b. 100 rounds full automatic

c. 100 rounds bursts (4 to 5 rounds each)

d. Repeat

After each 100 rounds fired, weapons will be cooled to ambient temperature by not less than 10 minutes of forced air cooling.

Under semi-automatic mode of fire, weapon shall be fired once every three seconds for 20 rds/min rate, and once every second for 60 rds/min rate.

Under full automatic mode of fire, one magazine of 20 rounds shall be fired every minute for weapons designated 20 rds/min and one magazine every 20 seconds for 60 rds/min rate.

When mode of fire is bursts, automatic bursts at four to five rounds each will be fired every 15 seconds for 20 rds/min rate and every five seconds for 60 rds/min rate.

ROUNDS FIRED (THOUSANDS)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Gage Inspection	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Borescoping	X					X					X				X						X					X					X
Cleaning	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trap Projectile	X					X					X				X						X					X					X
Velocity	X					X					X				X						X					X					X
Accuracy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Firing Sequence:

For weapons designated to be fired at rate of 100 rd/min on rate schedule weapon will be fired in full automatic mode only. One magazine will be fired every 12 seconds for 100 rds/min rate.

After each 100 rounds, weapon will be cooled to ambient temperature by not less than 10 minutes of forced air cooling.

Gage Inspection:

Weapon will be inspected with breech erosion gages. Record gage penetration, gage diameter, rifle serial number, barrel designation, and number of rounds fired prior to inspect .

Borescoping:

After breech erosion gage inspection, the weapons are to be borescoped at intervals designated in test plan. A visual inspection will be made of each chrome-plated bore to determine extent of chrome plating deterioration and coppering. Record comments, serial number of rifle, rounds fired prior to inspection, and barrel designation.

Trap Projectile:

At start of test and after rifle cooling, cleaning and borescoping at intervals shown in firing schedule, three rounds will be trapped in foam from each rifle. Identify each projectile with serial number of rifle, barrel designation and rounds fired previous to trapping.

Velocity:

After completion of projectile trapping (if projectiles are trapped), fire 10 rounds from each rifle for velocity. Record velocity using screens at five feet and 25 feet from muzzle. Record weapon serial number, barrel designation, velocity and previous rounds fired.

Accuracy:

After completion of velocity test (if velocity test is designated, see Firing Schedule), three 10 shot targets shall be fired from each rifle for accuracy at 100 yards using bench rest technique with muzzle and elbow support.

Rounds/Count:

All rounds fired during trapping, velocity, and accuracy shall accrue as rounds fired in test schedule.

	CUMULATIVE ROUNDS FIRED (HUNDREDS)																			
	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Gage Inspection	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Borescoping				X				X				X				X				X
Cleaning	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trap Projectile				X				X				X				X				X
Velocity				X				X				X				X				X
Accuracy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

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Small Arms Weapon Systems Directorate
GEN Thomas J. Rodman Lab, Rock Island Arsenal
CALIBRATION OF BREECH EROSION GAGE FOR
5.56MM CHROME-PLATED BORES
by Ronald E. Elbe

Rodman Laboratory Report R-TR-75-046
June 1975
27 pages, Including Figures and Tables
Unclassified Report

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2. 5.56mm Projectile
3. 5.56mm Barrels
4. Small ARms
5. Accuracy
6. Bore Erosion
7. Bore Erosion Gage
8. Chrome-Plated Barrels
9. Barrel Life

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1. M16A1 Rifle
2. 5.56mm Projectile
3. 5.56mm Barrels
4. Small Arms
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GEN Thomas J. Rodman Lab, Rock Island Arsenal
CALIBRATION OF BREECH EROSION GAGE FOR
5.56MM CHROME-PLATED BORES
by Ronald E. Elbe

Rodman Laboratory Report R-TR-75-046
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